EVALUATION OF EXPRESSWAY SAFETY COUNTERMEASURES OF KOREA

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ABSTRACT

The objective of this research is to evaluate the safety effectiveness of various countermeasures in Korea expressway. The existing methodologies for before-after safety evaluation, traditional naïve before-after evaluation, traditional comparison group method, and the Empirical Bayes(EB) methods have been applied to the Korea crash data to evaluate the safety effectiveness of four countermeasures(Decrease Posted Speed Limit, Install Speed Camera, Install Crash Cushion, Install Rumble Strips). The crash history data from 1994 to 2006 along with the roadway characteristics, AADT, and countermeasures installation data in Korea were assembles and the database combining the necessary information for the safety analysis were developed for each of the countermeasures. The analyses showed that:

For the countermeasures of decreasing the speed limit, all three evaluation approaches suggest the statistically significant safety effectiveness of decreasing the speed limit in total crashes although the size of estimated reduction varies across three approaches. For the countermeasures of installing speed camera, the naïve approach found statistically significant decrease in all types considered. For the countermeasure of installing crash cushion and installing rumble strips, the naïve and the comparison group approach found statistically significant decrease in total crash.

1. INTRODUCTION

1) Background and Objectives of Study

Although it is essential to conduct comprehensive safety evaluations by using appropriate statistical methods based on the crash data, installation of countermeasures data, and roadway geometric characteristic data, many of safety evaluations in Korea have been conducted by unconditionally adapting the naïve before-after comparisons, before-after evaluations with comparison groups (for the before-after data), ordinary linear regressions, Poisson regressions, or Negative Binomial regressions (for the cross-sectional data), and the limitations and pitfalls of each of those models have been ignored. The objective of this research is to evaluate the safety effectiveness of various countermeasures in Korea through various statistical crash analysis methods.

2) Literature Review

There has been considerable research on crash analysis and safety evaluation (see, 1-8, among many others). Hauer's 1997 book (11) discussed various observational before-after studies in safety analysis ranging from classical naïve and classical comparison methods to the EB approaches. Ever since then, the EB approaches have been employed by many researchers in safety evaluation of the countermeasures, and whenever the data are suspected to be subject to the selection bias, EB has been considered superior to the classical methods. Persaud and Lyon (12) provides an excellent review on the Empirical Bayes before-after safety studies including the basics of EB evaluation, the need for and validity of the EB approach, and addressing the issues that are critical to the proper conduct and interpretation of EB evaluations.

2. METHODOLOGY

The focus of this research is to investigate the Empirical Bayes approaches. However, the traditional methodologies such as the naïve before-after analysis and before-after analysis with comparison sites will also be briefly reviewed. The safety evaluation methodologies for the effectiveness of the countermeasures can be divided into two types: before-after evaluation methods and cross-sectional data analysis methods depending on the study design and the nature of the data, especially the availability of the information on the installation of the countermeasures. The before-after evaluation is usually considered superior to cross-sectional data analysis in that before-after evaluation can cope with site-to-site variability more effectively. In this chapter, before-after evaluation strategies will be discussed from two different perspectives of analysis approaches, classical, empirical Bayes approaches.

1) Statistical Analysis Methodology

(1) Traditional Methods

Two types of traditional methods will be reviewed: the naïve before-after evaluation method and the comparison group method.

Naïve Before-After Evaluation

The naïve before-after study often fail to distinguish the effect of treatment (countermeasure) from the effects of other factors that might have also changed from the before to the after period. The naïve before-after evaluation is valid only when it can be absolutely assured that there are no before-after differences caused by any other changes over time that can confound the effect of treatment. In the naïve before-after evaluation, the reduction in crashes is simply estimated by the difference between the average crash count in the before period and the average crash counts in the after period. The *t*-test is then conducted to determine if the reduction is statistically significant.

As a matter of fact, the assumption that there have been no changes from before to after periods other than the treatment is often violated. There will almost always be changes over time in traffic volume, vehicle mix, weather, etc. when the crash data of multiple years are analyzed. Because the naïve before-after evaluation does not control for those changes, the effect of treatment cannot be separated from those changes. The naïve before-after evaluation is the weakest of all before-after analyses and should be avoided whenever possible.

Comparison Group Method

The comparison group methodology is often effective in controlling for the effect of any extraneous factors that change over time as long as there is no concern of the regression-to-the-mean bias. The regression-to-the-mean is a selection bias which occurs when the sites for the treatment have been selected due to high crash history. Because of the random nature of crashes (crash frequency may fluctuate from year to year even if there are no changes in road design or operating scheme), there is a chance that the crash frequency would have decreased even if no countermeasure was implemented. As a result, the safety effect of a countermeasure would be overestimated if the regression-to-the-mean bias is not accounted for.

The underlying assumption in the comparison group method in safety evaluation is that the ratio of the crash reduction for the treatment site/sites (treatment group) before and after is the same as the ratio for the comparison group, had the countermeasure not been implemented at the treatment sites.

(2) Empirical Bayes (EB) Approach

The EB approach properly accounts for regression-to-the mean, large site-to-site variability, scarcity of crash data, and differences in traffic volumes between before and after study periods. The EB approach requires the reference group consisting of the sites (road segments) where there have been no changes of the countermeasure while they are similar to the treatment sites in roadway geometric characteristics based on which the Safety Performance Function (SPF) is estimated. Development and estimation of the SPF that is

subsequently used to obtain an estimate of the prior mean number of crashes before treatment is a critical component in an EB approach. The reference group is also used to predict the expected number of crashes in the after years for each treatment site, had the treatment not been applied.

The advantages of the Empirical Bayes (EB) approach over traditional methods are:

1. It helps to deal with the regression-to-mean bias in the data.
2. It properly accounts for the effect of the changes in traffic volume by using safety performance functions to represent the actual relationship between crashes and traffic volumes.
3. EB estimates tend to be more precise than estimates the estimates from the naïve before-after study or the comparison group method.
4. It allows the estimation of the entire time series of the expected accident counts over time.

3. DATA PREPARATION

1) Crash Database

The crash data consisting of detailed information about all crashes occurred between 1994 and 2006 along with the roadway characteristics, AADT, and speed limit change data (implementation date and location) were obtained from Korea Highway Corporation. The standard speed limit for the expressways in Korea is 100 km/hour

2) Roadway Segment Database

The roadway segment dataset was developed by first defining the road segments so that they have the same roadway characteristics such as the number of lanes, lane width, shoulder width, speed limit, control measures, and AADT within each segment.

3) Crash Data Aggregation

The crashes were assembled with the roadway segment database to provide the aggregated crash counts at each road segment for each year by crash severity (A, B, C), crash type, cause of crash as well as total crashes (the sum of all crashes at each road segment each year).

4. SAFETY EVALUATION RESULTS

The following countermeasures have been evaluated in this report:

1. Decrease Posted Speed Limit
2. Install Speed Camera
3. Install Crash Cushion
4. Install Rumble Strips

The crash history data from 1994 to 2006 along with the roadway characteristics, AADT, and countermeasures installation data in Korea were assembled and the databases combining the necessary information for the safety analysis were developed for each of the countermeasures. The data for each of the countermeasures #1 - #4 are observational before-and-after data in nature. The road segments with the countermeasures installed (treatment sites) have known installation dates and multiple years of before and after crash data.

1) Countermeasure 1: Speed Limit Decrease

The standard speed limit for the expressways in Korea is 100 km/hour. There have been changes in the speed limit (decreasing it to 80 km/hour) at some locations selectively due to high crash history in years 1995, 2000, 2001, and 2003. The before study period extended from the beginning of the first year for which crash data for the site were available (1994) to the end of the last calendar year before the change in the speed limit. The after study period extended from the beginning of the year after the speed limit was changed to the end of the last year for which crash data for the site were available (2006).

Crashes of the following types were analyzed for safety evaluation of speed limit

decrease:

1. Total: Crashes of all types
2. Speed: Crashes with “Cause of accident” reported as speed or speed violation
3. A: Crashes of severity A
4. B: Crashes of severity B
5. C: Crashes of severity C

Comparing Before-After Safety Evaluation Results Obtained by Different Methods for Speed Limit Decrease

The results from different evaluation approaches have been compared. Table 1 and Figure 1 present the estimated percent crash reduction, $100\left(1-\hat{\theta}\right)$, for speed limit decrease by four different approaches.

Table 1 Percent crash reduction for speed limit decrease estimated by different methods

$100\left(1-\hat{\theta}\right)\%$	Crash Type				
Approach	**Total**	**Speed**	**A**	**B**	**C**
Naïve	**42.3**	**40.1**	21.0	**51.6**	**40.2**
Comparison Group	**25.7**	**46.6**	-132.4	-8.1	**33.6**
EB	**15.0**	17.11	-40.4	-7.9	**21.1**

Note: Statistically significant results (with 95% confidence/probability) are shown in bold.

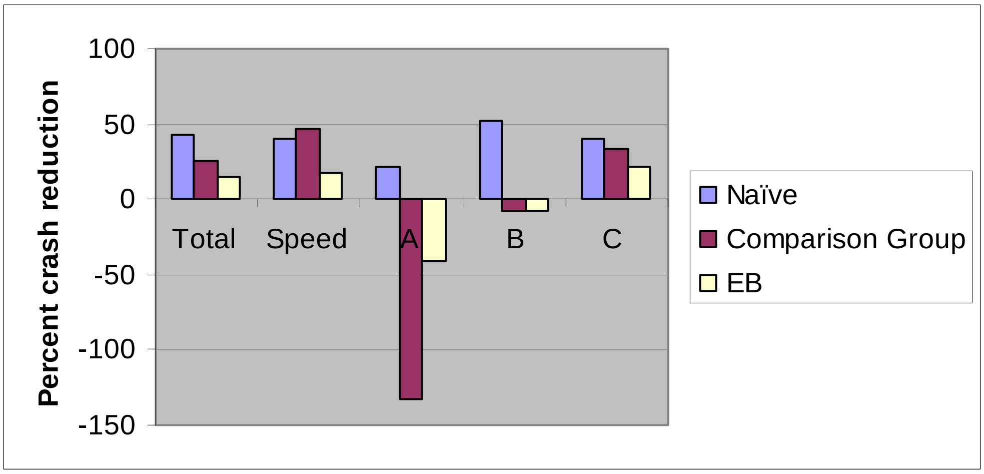

Figure 1 Estimated percent crash reduction for speed limit decrease

The following observations can be made from Table 1 and Figure 1:

- For Total accidents and Type C accidents, all four approaches suggest the statistically significant safety effectiveness of speed limit decrease, and for Speed accidents all but the EB method suggest the statistically significant safety effectiveness of speed limit decrease.
- The percent crash reduction estimated by naïve before-after evaluation is the largest among the three approaches in general, and it seems to have been overestimated.
- The comparison group approach leads to similar conclusions for Total, Speed and Type C accidents.
- For Type A and B accidents, there is a huge variation in the results from three approaches, which seems to have been caused by the scarce data.

2) Countermeasure 2: Install Speed Camera

Speed cameras have been installed extensively throughout the expressways in Korea from 1997 to 2006. The before study period extended from the beginning of the first year for which crash data for the site were available to the end of the last calendar year before the speed camera was installed. The after study period extended from the beginning of the year after the speed camera was installed to the end of the last year for which crash data for the

site were available. Because there are no after data for the sites with the implementation year 2006, the sites corresponding to the implementation year 2006 were excluded from the analysis. Also, the sites with the AADT missing completely during the before years were excluded because the SPF predictions cannot be made for those sites. The resulting number of treatment sites was 505 corresponding to 1908.25 km of roadways.

Due to a potential spillover effect of a speed camera (i.e., a speed camera may affect the neighboring sites) a comparison group/reference group was not selected from the neighboring sites of the treatment sites, but was selected from the region that the drivers do not suspect if there would be speed camera installed. In conducting the safety evaluation using a comparison group approach or an EB approach, it is important to make sure that the comparison group or reference group is unaffected by the treatment because ignoring such spill over effect will lead to underestimation of crash reduction

Crashes of the following types were analyzed for safety evaluation of speed camera:

1. Total: Crashes of all types
2. Speed: Crashes with "Cause of accident" reported as speed or speed violation
3. A: Crashes of severity A
4. B: Crashes of severity B
5. C: Crashes of severity C
6. Severe: Crashes of severity B or severity C

Comparing Before-After Safety Evaluation Results Obtained by Different Methods for Speed Camera

The results from different evaluation approaches have been compared. Table 2 and Figure 2 present the estimated percent crash reduction, $100\left(1-\hat{\theta}\right)$, for speed camera by four different approaches.

Table 2 Percent crash reduction for speed camera estimated by different methods

$100\left(1-\hat{\theta}\right)$%	Crash Type					
Approach	**Total**	**Speed**	**A**	**B**	**C**	**Severe**
Naïve	**47.5**	**52.3**	**75.9**	**74.1**	**34.6**	**74.2**
Comparison Group	4.5	-8.2	-4.2	2.5	4.3	1.8
EB	**6.7**	3.5	7.9	**17.2**	4	**16.1**

Note: Statistically significant results (with 95% confidence/probability) are shown in bold.

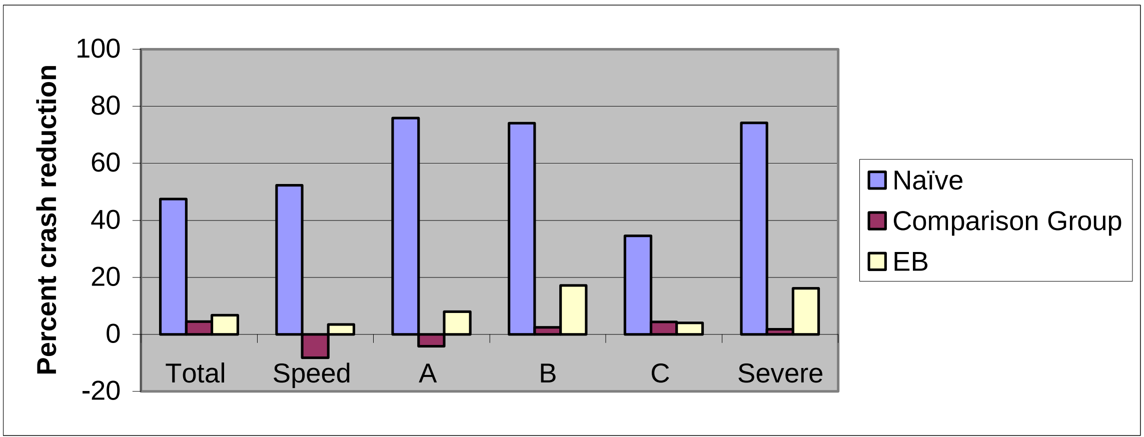

Figure 2 Estimated percent crash reduction for speed camera

The following observations can be made from Table 2 and Figure 2:

- The percent crash reduction estimates obtained by naïve before-after evaluation are considerably larger than those from the other approaches, and they seem to have been significantly overestimated.
- The comparison group approach lead to conclusions; the safety effectiveness of speed camera was not significant for any of the crash types considered here.

- The percent reduction estimates for the EB approach lie between those from the naïve approach and the comparison group approach.

3) Countermeasure 3: Install Crash Cushion

Crash cushions have been installed extensively at ICs in Korea from 1996 to 2006. The before study period extended from the beginning of the first year for which crash data for the site were available to the end of the last calendar year before the crash cushion was installed. The after study period extended from the beginning of the year after the crash cushion was installed to the end of the last year for which crash data for the site were available.

Because there are no sites with crash cushion installed in Kyung-In-Sun, Kyung-In2, or Seohaean-Sun, the segments in those roadways were excluded from the comparison group/reference group. Also the treatment sites with the implementation year 2006 were excluded from the analysis because there are no after data available for them. The sites with the AADT missing completely during the before years were excluded because the SPF predictions cannot be made for those sites. The resulting number of treatment sites (ICs) was 88. Crashes of the following types were analyzed for crash cushion: Total, B, C, and Severe.

Comparing Before-After Safety Evaluation Results Obtained by Different Methods for crash cushion

The results from different evaluation approaches have been compared. Table 3 and Figure 3 present the estimated percent crash reduction, $100\left(1-\hat{\theta}\right)$, for crash cushion by four different approaches.

Table 3 Percent crash reduction for crash cushion estimated by different methods

$100\left(1-\hat{\theta}\right)$	**Crash Type**			
Approach	**Total**	**B**	**C**	**Severe**
Naïve	**25.0**	**52.2**	8.1	**53.2**
Comparison Group	**19.0**	16.6	**24.4**	17.8
EB	6.8	-1.4	3.3	1.0

Note: Statistically significant results (with 95% confidence/probability) are shown in bold.

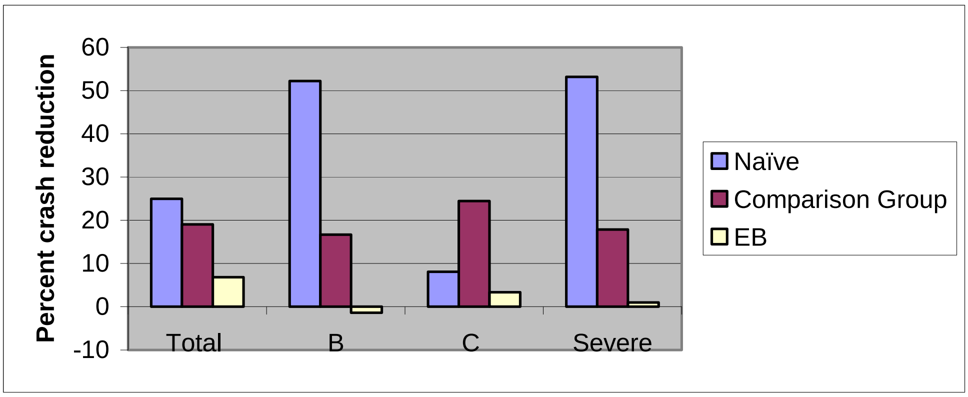

Figure 3 Estimated percent crash reduction for crash cushion

The following observations can be made from Table 3 and Figure 3:

- The percent crash reduction estimates for Type B and Severe accidents obtained by naïve before-after evaluation are considerably larger than those from the other approaches, which seem to have been significantly overestimated.
- The EB approach lead to similar conclusions; the safety effectiveness of crash cushion was not significant for any of the crash types considered here.
- The percent reduction estimates for the EB approach lie between those from the naïve approach and the comparison group approach.
- For Total accidents and Type C accidents, the comparison group approach suggests statistically significant safety effectiveness of crash cushion.

4) Countermeasure 4: Install Rumble Strips

Rumble strips are installed in part of expressways in Korea. Implementation took place in years 2003, 2004, 2005, and 2006. For the rumble strip safety evaluation, 7 years of the crash data obtained from 2000 to 2006 (instead of 13 years of the crash data from 1994 to 2006) were utilized because the rumble strips had not been installed until 2003 and the AADT within each segment in the roadway segment database were available only from 2000. The before study period extended from the beginning of the first year (2000 in this case) for which crash data for the site were available to the end of the last calendar year before the rumble strips were installed. The after study period extended from the beginning of the year after the rumble strips were installed to the end of the last year for which crash data for the site were available.

Because there are no sites with rumble strips installed in 88-Sun, Kyung-In-Sun, or Honam-Sun, the segments in those roadways were excluded from the comparison group/reference group. Also the treatment sites with the implementation year 2006 were excluded from the analysis because there are no after data available for them. The sites with the AADT missing completely during the before years were excluded because the SPF predictions cannot be made for those sites. The resulting number of treatment sites was 123 corresponding to 285.6 km of road segments. For Rumble strips, Total accidents, Severe accidents, Type C accidents, and the following types of crashes were additionally analyzed:

1. DD: Crashes caused by drowsiness or distraction
2. DDO: Crashes caused by drowsiness, distraction, or oversteering
3. Day: Crashes that occurred when the light condition was described as “daylight”, “bright”, or “light”.
4. Night: Crashes that occurred when the light condition was described as “dark”, “dawn”, “dusk”, or “night”.
5. Wet: Crashes that occurred when the road surface condition was described as “wet”, “icy”, or “snowy”.

Comparing Before-After Safety Evaluation Results Obtained by Different Methods for Rumble Strips

The results from different evaluation approaches have been compared. Table 4 and Figure 4 present the estimated percent crash reduction, $100\left(1-\hat{\theta}\right)$, for rumble strips by four different approaches.

Table 4 Percent crash reduction for rumble strips estimated by different methods

$100\left(1-\hat{\theta}\right)$	Crash Type							
Approach	**Total**	**Severe**	**C**	**DD**	**DDO**	**Day**	**Night**	**Wet**
Naïve	**29.4**	**33.9**	**28.6**	**30**	**26.6**	**27.5**	**31.9**	18.6
Comparison Group	**20.6**	-36.2	**27.7**	9.2	16.8	**27.9**	-6.3	35.3
EB	7.6	**-18.3**	13.8	**39.5**	**24**	**21.5**	-5.2	**37.6**

Note: Statistically significant results (with 95% confidence/probability) are shown in bold.

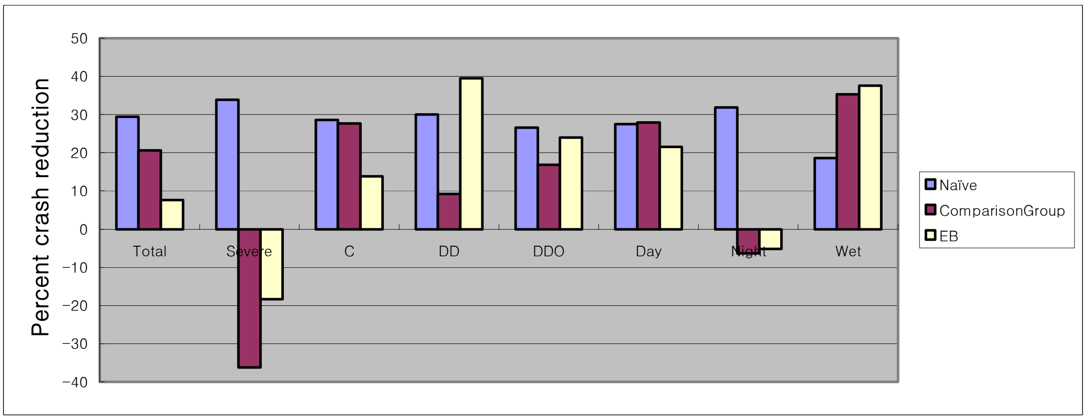

Figure 4 Estimated percent crash reduction for rumble strips

The following observations can be made from Table 4 and Figure 4:

- For Day accidents, all three approaches suggest the statistically significant safety effectiveness of rumble strips (ranging from 21.5%~30.6%), and for C accidents all but the EB method suggest the statistically significant safety effectiveness of rumble strips (ranging from 27.7%~28.6%),.
- The naive approach suggests statistically significant positive safety effect of rumble strips on Severe and Night accidents while the other approaches suggest none to negative safety effect.
- Both naive approach and EB approach suggest a statistically significant positive safety effect of rumble strips on DD and DDO accidents.
- Only EB approach suggest a statistically significant positive safety effect of rumble strips on Wet accidents.

4. SUMMARY AND CONCLUSIONS

The objective of this research was to evaluate the safety effectiveness of various countermeasures in Korea using various statistical analysis methodologies. The existing methodologies for before-after safety evaluation, traditional naïve before-after evaluation, traditional comparison group method, and the Empirical Bayes (EB) methods have been reviewed and their advantages and disadvantages were discussed.

The Empirical Bayes methods, as well as the traditional naïve before-after evaluation and comparison group method, have been applied the Korea crash data to evaluate the safety effectiveness of four countermeasures:

1. Decrease Posted Speed Limit
2. Install Speed Camera
3. Install Crash Cushion
4. Install Rumble Strips

The crash history data from 1994 to 2006 along with the roadway characteristics, AADT, and countermeasures installation data in Korea were assembled and the databases combining the necessary information for the safety analysis were developed for each of the countermeasures.

The results for each countermeasure are as follows:

- For the countermeasure of decreasing the speed limit, all three evaluation approaches suggest the statistically significant safety effectiveness of decreasing the speed limit in Total and Type C accidents although the size of estimated reduction varies across four approaches. The naïve approach found statistically significant decreases in Total(42.3%), Speed(40.1%), Type B(51.6%), and Type C(40.2%) accidents while the comparison group approach found statistically significant decreases in Total(25.7%), Speed(46.6%) and Type C(33.6%) accidents. The EB approach found that there were statistically significant decreases in Total (15.0%) and Type C (21.1%) accidents.
- For the countermeasure of installing speed camera, the naïve approach found statistically significant decreases in all crash types considered: Total(47.5%), Speed(52.2%), Type A(75.9%), Type B(74.1%), Type C(34.6%), and Severe(74.2%) accidents while the comparison group approach did not find any statistically significant decreases in any of those crash types. The EB approach found statistically significant decreases in Total accidents(6.7%) Type B(17.2%), and Severe(16.1%).
- For the countermeasure of installing crash cushion, the naïve approach found statistically significant decreases in Total(25.0%), Type B(52.2%), and Severe(53.2%) accidents while the comparison group approach found statistically significant decreases in Total(19.0%) and Type C(24.4%). The EB approach found no statistically significant changes in any of Total, Type B, Type C, and Severe accidents. This finding does not imply that there is no safety benefit (assessed by EB approach) of crash cushion, but it suggests a need for more crash data to be analyzed. Also, crashes of other types or different aspects of crashes (e.g., relative proportions of crashes of different severites) may need to be investigated.
- For the countermeasure of rumble strips, the naïve approach found statistically significant decreases in Total(29.4%), Severe(33.9%), Type C(28.6%), DD(30%), DDO(26.6%), Day(27.5%), Night(31.9%) accidents while the comparison group approach found statistically significant decreases in Total(20.6%), Type C(27.7%),

and Day(27.9%) accidents. The EB approach found statistically significant decreases in DD(39.5%), DDO(24%), Day(21.5%), and Wet(37.6%) accidents.

The general conclusions that can be drawn from this research are:

- The EB methods can overcome the limitations in the crash evaluations by the traditional methods such as the regression-to-the-mean bias, and are recommended for obtaining statistically defensible conclusions for the safety evaluation studies in Korea.
- Although the EB methods are easier to implement, there is some chance that the safety effectiveness by the EB methods can be overestimated. Also, the EB estimates may be invalid if the Safety Performance Functions are not developed correctly.
- In general, the naïve before-after evaluation significantly overestimates the safety effectiveness of the countermeasures and is not recommended for a sound safety analysis because the method does not account for the regression-to-the-mean bias and any changes in extraneous factors.
- The comparison group method can be effective in controlling for the effect of any extraneous factors that change over time as long as a suitable comparison group is selected and there is no concern of the regression-to-the-mean bias. When those conditions are met, it often leads to similar conclusions as those from the more advanced Bayesian methods. If either condition is violated, however, the results from the comparison group method will be invalid and very misleading.

REFERENCES

1. Abbess, C., D. Jarett, and C.C. Wright. Accidents at Blackspots: estimating the Effectiveness of Remedial Treatment, With Special Reference to the "Regression-to-Mean" Effect. *Traffic Engineering and Control*, Vol. 22, No. 10, 1981, pp. 535-542.
2. Hauer, E., J. C. N. Ng, and J. Lovell, Estimation of Safety at Signalized Intersections. In *Transportation Research Record* 1185, TRB, National Research Council, Washington, D.C., 1988, pp. 48-61.
3. Persaud, B.N. and L. Dzbik, Accident Prediction Models for Freeways. In *Transportation Research Record* 1401, TRB, National Research Council, Washington, D.C., 1993, pp. 55-60.
4. Persaud, B., Retting, R., Lyon, C., 2004. Crash reductions following installation of centre-line rumble strips. Accident Anal. Prev. 36, 1073–1079.
5. Oh, J., C. Lyon, S. P. Washington, B.N.Persaud, and J. Bared. Validation of the FHWA Crash Models for Rural Intersections: Lessons Learned. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1840*, Transportation Research Board of the National Academies, Washington, D.C., 2003, pp 41-49.
6. Lord, D., A. Manar, and A. Vizioli, Modeling Crash-Flow-Density and Crash-Flow-V/C Ratio for Rural and Urban Freeway Segments. *Accident Analysis & Prevention*, Vol. 37, No. 1, 2005, pp. 185-199.
7. Miaou, S.-P., and J. J. Song. Bayesian ranking of sites for engineering safety improvements: Decision parameter, treatability concept, statistical criterion and spatial dependence. *Accident Analysis and Prevention*, Vol. 37, No. 4, 2005, pp. 699-720.
8. Persaud, B.N., and E. Hauer. Comparison of Two Methods for Debiasing Before-and-After Accident Studies. In Transportation Research Record 975, TRB, National Research Council, Washington, D.C., 1984, pp.43-49.
9. Hauer, E. On the Estimation of the Expected Number of Accidents. Accident Analysis and Prevention, Vol. 18, No.1, 1986, pp.1-12.
10. Hauer, E., *Observational Before-After Studies in Road Safety: Estimating the Effect of Highway and Traffic Engineering Measures on Road Safety.* Oxford, United Kingdom, Pergamon Press, Elsevier Science, Ltd., 1997.
11. Persaud, B., and Lyon, C. Empirical Bayes before-after safety studies: Lessons learned from two decades of experience and future directions, Accident Analysis & Prevention 39, 2007, 546-555.
12. Campbell, D. T., and Stanley, J. C. Experimental and quasi-experimental designs for research, Chicago: Rand McNally, 1963.
13. Harwood, D. W., K. M. Bauer, I. B. Potts, D. J. Torbic, K. R. Richard, E. R. K. Rabbani, E. Hauer, and L. Elefteriadou. *Safety Effectiveness of Intersection Left- and Right-Turn Lanes.* Report FHWA-RD-02-089. FHWA, U.S. Department of Transportation, July 2002.